



# JEDI Marine and Hydrokinetic Model: User Reference Guide

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## **Executive Summary**

The Jobs and Economic Development Impact Model (JEDI) for Marine and Hydrokinetics (MHK) is a user-friendly spreadsheet-based tool designed to demonstrate the economic impacts associated with developing and operating MHK power systems in the United States. The JEDI MHK User Reference Guide was developed to assist users in using and understanding the model. This guide provides information on the model's underlying methodology, as well as the sources and parameters used to develop the cost data utilized in the model. This guide also provides basic instruction on model add-in features, operation of the model, and a discussion of how the results should be interpreted.

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## Introduction

The Marine and Hydrokinetic (MHK) Jobs and Economic Development Impact Model (JEDI) is designed to demonstrate the economic impacts associated with developing and operating MHK power systems in the United States. Hydrokinetic technologies include wave, tidal, river hydrokinetic, and ocean current technologies. MHK is an emerging renewable technology sector with limited deployed capacity (about 5 MW) to date. Unlike wind and other renewable and conventional technologies, there are relatively few examples of commercial applications operating today and little publicly available cost data [installation or operation and maintenance (O&M)] for these systems. In the absence of historical cost data, engineering cost models were used to develop a set of reference cost data. While the data incorporates significant uncertainties, we believe the information presented in this model represents the most detailed, current, and accurate information available to the public at this time.

The primary goal in developing this model is to provide a tool for MHK developers, renewable energy advocates, government officials, decision makers, and other potential users to easily identify the potential local economic impacts associated with constructing and operating MHK power systems. As an emerging technology with associated installation and operating uncertainties, users are advised to use the preliminary results with caution.

Consistent with these goals, strong emphasis was placed on designing the model in a user-friendly format that can be easily modified—reflecting different levels of project-specific information and user skill. This ensures the greatest flexibility for inexperienced spreadsheet users, those unfamiliar with economic impact analysis, and more experienced and knowledgeable users who have a need for this specific type of analysis.

The model was designed by Marshall Goldberg of MRG & Associates<sup>1</sup> in 2010 under contract to the National Renewable Energy Laboratory (NREL). Reference cost input data and technology assumptions were developed by Mirko Previsic of RE Vision Consulting under contract with the U.S. Department of Energy.<sup>2</sup>

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<sup>2</sup> Mirko Previsic can be reached at [mirko@re-vision.net](mailto:mirko@re-vision.net).

## Methodology

The model offers users the capability to analyze four different system types. These include: wave, tidal, ocean current, and river hydrokinetic. Given basic information about a marine or hydrokinetic project (minimally, the state it is to be located in, the year of construction, and the size of the system), users can estimate not only what a project will cost (i.e., specific expenditures) but also the number of jobs, income (i.e., wages and salary), and economic activity that will accrue to the state (or local region) from the project.<sup>3</sup> Due to the nature and availability of cost and operating data on these emerging technologies, the model has been calibrated to one deployment scale (MW) for each of the system types available. To evaluate these impacts, input-output or multiplier analysis is used.

Input-output models were originally developed to trace supply linkages in the economy. For example, they show how purchases of underwater electrical cable not only benefit cable manufacturers but also the metal industries and other businesses supplying inputs to those manufacturers. The benefits that are ultimately generated by expenditures for MHK systems depend upon the extent to which those expenditures are spent locally and the structure of the local economy. Consistent with the spending pattern and state-specific economic structure, different expenditures support a different level of employment, income, and output.

Input-output analysis can be thought of as a method of evaluating and summing the impacts of a series of effects generated by an expenditure (i.e., input). To determine the total effect of developing an MHK system, three separate impacts are examined for each expenditure. Often these effects are referred to as direct, indirect, and induced effects. However, to provide results that are more intuitive, in NREL's MHK JEDI model these impacts are labeled as follows:

**On-site labor and professional services impacts:** the on-site or immediate effects created by an expenditure. When installing an MHK system, these impacts refer to the on-site jobs of the contractors and crews hired to install the system.

**Local revenues and equipment and supply chain impacts:** effects that accrue in supporting industries. These results are driven by the increase in demand for goods and services from direct on-site project spending. Businesses and companies included in the second tier of economic activity include construction material and component suppliers, analysts and attorneys who assess project feasibility and negotiate contract agreements, banks financing the projects, and all equipment and manufacturers of replacement and repair parts.

**Induced impacts:** effects driven by reinvestment and spending of earnings by direct and indirect beneficiaries. Induced results are often associated with increased business at local restaurants, hotels, and retail establishments but also include child care providers and any other entity affected by increased economic activity and spending occurring at the first two tiers.

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<sup>3</sup> Although the JEDI model is designed to provide state-level analysis, the model also includes a "User Add-in Location" feature. This feature allows users to import specific county or region-level multipliers and personal expenditure patterns to localize the analysis to a smaller or larger region than the state level. For more detail on this procedure, refer to the User Add-in Location section description in this document.



The sum of these three sets of impacts yields a total effect resulting from a single expenditure. To generate the specific impact at each level, state-specific multipliers and personal expenditure patterns are used. These state-by-state multipliers—employment, wage, and salary income and output (economic activity)—and personal expenditure patterns are adapted from the IMPLAN model Version 3.0 using 2008 state data.<sup>4</sup> To calculate the results, the expenditures brought about by investments in developing MHK systems are matched with their appropriate sector-specific multiplier.

Consistent with an analysis of this type and scope, the assumptions used play an important role in influencing the results. Thus, to accommodate the greatest level of flexibility in user skill level and availability of specific detailed project information, the model is designed to incorporate model default values or new values entered by the user. The default values represent a reasonable expenditure pattern for constructing and operating each of the four types of MHK systems in the United States and the share of expenditures spent locally. The default expenditure pattern is based on an extensive review of MHK data (see Data Sources at the end of this document).

Admittedly, not every project will follow this exact “default” pattern for expenditures. In fact, due to the uncertainties associated with these emerging technologies, the default cost pattern is only available for the specific system size noted in the model. Users desiring to model alternative system sizes must enter the detailed cost data for each category noted. Location, financing arrangements, and numerous site-specific factors influence the installation and operating costs in addition to project size. Similarly, the availability of local resources, including labor and materials, and the availability of locally manufactured components can have a significant effect on the costs and the economic impacts that accrue to the state or local region. To the extent the user has and can incorporate project-specific data and the share of spending that is expected to occur locally, the more localized the impact analysis will be.

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<sup>4</sup> IMPLAN (Impact Analysis for Planning) is a social accounting and impact analysis tool. Minnesota IMPLAN Group (MIG, Inc). [www.IMPLAN.com](http://www.IMPLAN.com). Accessed January 2011.

## Inputting Data and Running the Model

The JEDI model is designed for all levels of users, requiring minimal experience with spreadsheets and no background in economic modeling. The model includes “online” instructions explaining how to proceed with entering data for analysis and informative “comments” assisting users to understand the type of data required in specific cells. The comments are viewed by pointing the cursor to the triangle located in the corner of the cell.

*Please note: The model formulas and default data are protected, and user-modified data is only applicable to the specific analysis users are performing while the model is open. If unwanted changes are made, click on the “Restore Default Values” button on the ProjectData page or merely close the model and reopen it to start over with the initial model default values.*

Users with little or no experience with MHK systems or economic impact analysis need only, at a minimum, choose the state in which the system will be installed, enter the year the system will be installed, choose a system type, and accept the default reference system size. The user can then choose to accept all project defaults (or review and edit the defaults) and go directly to Summary Impacts to view the results of the analysis. *Please note: To modify the defaults (i.e., not utilize the default model values), enter an “N” in the designated cell on the ProjectData page to incorporate the new data in the analysis.*

Users with more experience with MHK systems or economic impact analysis (e.g., those with more project-specific information on costs and expenditures, financing, taxes, and local shares of spending) can review and choose to (or choose not to) modify the default values and then go to Summary Impacts to view the results of the analysis. The expenditure values are entered in purchaser prices. The model then automatically allocates the expenditures to the respective producing industries (margins).

Once the analysis is complete, users have several options for saving the data and results. If a hard copy is desired, users can choose to print (from the summary page) by clicking on the “Project Data Summary and Summary Results” (the data and results contained on the summary page) button and print the “Detailed Project Data” (a detailed version of all cost and expenditure data used in the analysis) by clicking on the respective button. Alternately, users can export the data and results to a separate Excel file by clicking the “Export” button. If users wish to save the entire model (with the user-modified data) for future use or reference, merely click the “Save” button on the toolbar, name the model, and choose a directory. Changing the name ensures the original model (with model defaults) is kept intact for future analysis. Users always have the option to simply “block” and “copy” any desired cells to another spreadsheet or document.

## Interpreting the Results

Regardless of how much project-specific data is entered by the user, JEDI provides sufficient information to help users (and others) better understand the magnitude of the economic impacts associated with the system being analyzed.

The model provides basic project information to help users identify the magnitude of the construction/installation-related spending and ongoing O&M expenditures. The model also identifies the portion of the spending that occurs locally (again, this is determined by the “local share” values—default or user-modified—used in the model for each of the expenditures). Similarly, the model identifies local spending on debt and equity payments, property taxes, and land lease payments, if applicable.

In addition to the basic system information and costs, the model analyzes and reports the local job earnings and output (economic activity) generated as a result of the project for the installation phase and for the ongoing operations phase. For the short-term installation phase, the impacts are broken out by project development and on-site labor impacts, equipment and supply chain impacts, and induced impacts.

For example, users interested in understanding the economic impacts from installing a 10 MW ocean current MHK system in Oregon, to be built in the year 2012 at a cost of \$6,777/kW, can easily and quickly find the answers by using the JEDI model. By inputting these few pieces of information into the model (in project description) and accepting the model defaults, users find (by going directly to the summary results) that the construction of the plant will support almost 158 local jobs (full-time equivalent for a year) and generate over \$27 million in local economic activity over the 24-month installation period.<sup>5</sup> Of the total jobs, users see that approximately 23 are directly in the construction sector.

This same project, once it is up and running, continues to benefit the state. We see a total of 27 jobs (full-time equivalent during each year of operation) supported, with just over a third (9.5 jobs) of these directly employed by the MHK plant. The total annual local economic activity supported by the ongoing operation is \$4 million.

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<sup>5</sup> Based on the 24-month construction period, the total 158 jobs is the equivalent of an annual average of 79 full-time equivalent jobs supported in each of the years.

## Caveats

Several important caveats should be noted at this point. First, the intent of the MHK impact model is to construct a reasonable profile of investments (i.e., MHK system construction/installation and operating costs) and demonstrate the magnitude of the economic impacts that will likely result, assuming a project occurs during the stated period of analysis. Given the emerging nature of the industry, expected changes in MHK system costs (as the technologies mature) and changes in industry and personal consumption patterns in the economy are likely—with this in mind the analysis is not intended to provide a precise forecast. Rather, the analysis should be viewed as preliminary and as an approximate estimate of the overall magnitude of the impacts. Similarly, since the model is designed solely to analyze only the specific deployment sizes identified in the model (i.e., unless a user has detailed knowledge of alternate systems and specific cost inputs to revise the defaults), users are cautioned against extrapolating the impacts to similar but different sized projects. (See the discussion on costs, learning curves, and economies of scale later in the document.)

Second, the analysis is specific to developing MHK systems only and thus is considered a gross analysis. That is, it does not reflect net impacts associated with alternate spending (such as constructing and operating other types of electricity generating systems or power plants) or replacement of existing power generation resources.

Third, the analysis assumes the output from the MHK system and the specific terms of a power purchase agreement generate sufficient revenues to accommodate the equity and debt repayment and annual operating expenditures. To the extent additional revenues (i.e., profits and tax advantages above actual costs) accrue to the project owner, there will be added benefits. These benefits are not included in the analysis.

## User Add-in Location Feature

The initial design for the JEDI model provided for state-level impact analysis. However, it was apparent that many potential users might wish to perform a similar level of analysis for a smaller or more localized region (such as an individual county or group of counties) or for a larger region (such as a group of states) to better capture the regional benefits. Unfortunately, the high cost of including multiplier and expenditure data in the model for every county in the United States and the complexities associated with designing the model to analyze the endless number of possibilities for combining counties and states made this impractical.

However, to accommodate users who desire to do this level of analysis, a User Add-in Location feature is provided in the model. This feature allows users with the capability to derive or obtain the necessary data to complete analysis for a specific region of interest other than the state level included with the base model. The necessary inputs include direct, indirect, and induced multipliers for employment, earnings and output (per million dollars change in final demand), and personal consumption expenditure patterns (i.e., average consumer expenditures on goods and services—calculated as a percentage, in decimal format, for each industry, totaling 100% combined) for the 14 aggregated industries. The aggregated industries include:

1. Agriculture
2. Construction
3. Electrical equipment
4. Fabricated metals
5. Finance, insurance, and real estate
6. Government
7. Machinery
8. Mining
9. Other manufacturing
10. Other services
11. Professional services
12. Retail trade
13. Transportation, communication, and public utilities
14. Wholesale trade.

For IMPLAN users, gathering the necessary data will require several steps:

1. Purchase the desired county or state-level data files
2. Using IMPLAN Version 3 software, create a new model with the desired region (one county, group of counties, or group of states)
3. Construct the model
4. Aggregate the model. This step requires the user to create a new 14-industry aggregation scheme to aggregate the new model. Alternatively, the JEDI aggregation template used to aggregate the state multipliers into the 14 industries noted above is available by request.
5. Reconstruct the model
6. Export household local commodity demand (personal consumption expenditures) and multipliers for employment, employee compensation, and output to spreadsheet files
7. Format data contained in each of these files to input (i.e., cut and paste) into the respective location (MyCounty for a single county or MyRegion for a group of counties or states) in the User Add-in Location worksheet in JEDI.

Once the user data is entered into the JEDI model, the user need only identify the location of the MHK system (in the project description section of the ProjectData worksheet) as MyCounty or MyRegion, depending upon the type of data and where the data is entered, and proceed with the analysis.

For non-IMPLAN users or those unfamiliar with input-output modeling, there are several options for gathering the necessary data to perform specific county or regional analysis. These include:

1. Follow a similar process as that noted above to derive the aggregated multiplier and consumer expenditure data from another input-output modeling tool
2. Purchase the necessary data (aggregated multiplier and consumer commodity demand—see description above) from someone skilled in input-output modeling
3. Purchase the necessary data (aggregated multiplier and consumer commodity demand—see description above) from Minnesota IMPLAN Group, Inc. (IMPLAN).

## Accessing and Viewing Model Work Areas

To help ensure the JEDI model is as user-friendly as possible and to adhere to strict licensing restrictions on proprietary data contained in the model (IMPLAN), several of the intermediate work areas have been hidden from view. These areas include: default data, calculations, deflators, household expenditures, and multipliers. If desired, default data, calculations, and deflators, can be viewed by users by simply clicking on the respective worksheet. Viewing the worksheets will not affect the operation of the model. *Please note: The data and formulas contained in all work areas are protected (except those specifically designed to accept user input) and should not be modified. Modifying any of the data or formulas could seriously impact the accuracy or usability of the model.*

## Data Sources

Unlike more mature renewable energy sectors, historical cost data available in this sector is limited to a few pilot and demonstration projects worldwide. Prototypes or single device deployments tend to be poor indicators of true technology costs because cost profiles tend to be dominated by infrastructure, tooling, and mobilization costs. As such, the current state of this technology provides unique challenges in the evaluation of installation and operations cost profiles and relies heavily on predictive cost models and engineering cost assessments.

Cost assessments carried out to date have shown that the critical issue with respect to developing industry-representative cost profiles is that they are dominated by cost uncertainty (RE Vision Consulting 2010). These cost uncertainties are best addressed using a comprehensive techno-economic approach. Over the last 6 years, a suite of parametrically driven techno-economic models have been developed for use in a wide range of siting and economic studies for a variety of clients (RE Vision Consulting 2010).

These techno-economic models were developed in close collaboration with device manufacturers that have undergone a substantial amount of technical development and hence have attained a reasonable technical maturity. This approach reduces technological uncertainties and assumptions to a minimum. However, because many data-points are commercially sensitive and were obtained under strict non-disclosure provisions, details on these cost assessments cannot be shared with the general public. Resources of publicly available cost studies of wave, tidal, and river systems are included at the end of this document.

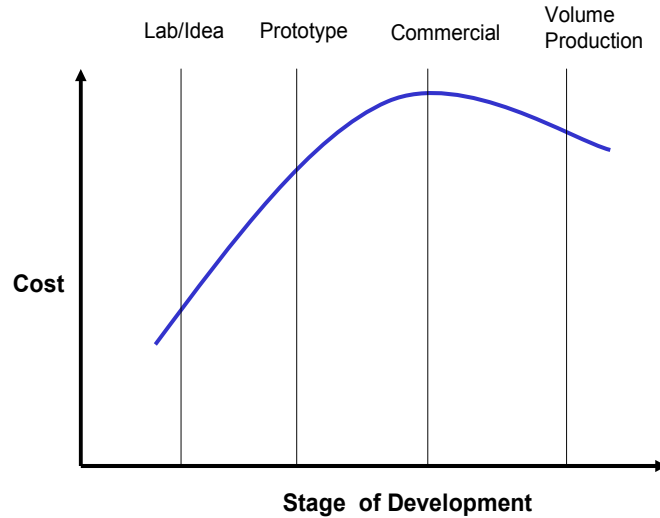
In order to provide representative inputs to the JEDI model, techno-economic modeling results (e.g., RE Vision Consulting 2010) and publicly available cost studies (see resources list) were revisited, and cost profiles were indexed and normalized to 2010 constant dollars. Where required, technical specifications were updated to reflect more recent technological developments by device manufacturers. In order to put the baseline reference cost into perspective, a few fundamental driving considerations are outlined below.

### Cost Uncertainty Ranges

Prior studies have indicated that manufacturers typically underestimate costs in the early stages of development. As the technologies progress toward commercial maturity, such cost projections increase. The actual build and operational cost of a pilot device or a pilot tidal farm reveals a complete picture of how different factors affect life cycle cost.

Once a technology reaches commercial maturity, volume production begins driving down costs. Figure 1 shows the typical cost projection as a function of design maturity.





**Figure 1. Cost projection as a function of development status**

Based on experience estimating energy project cost, the Electric Power Research Institute (EPRI) has developed a cost estimate rating table that assesses the likely range of uncertainty based on the technology’s design maturity and the amount of detail going into the cost estimate (see Table 1). This study uses cost estimates from the simplified level of detail and technology’s stage of maturity at the pilot level, thereby yielding a likely cost uncertainty of –30% to +30% on the overall life cycle cost. However, cost uncertainties in sub-categories can be much larger and some of the uncertainties cancel themselves out at the system level.

**Table 1. EPRI Cost Estimate Rating Table Showing the Predicted Cost Uncertainty Range (in %) as a Function of Technology Maturity (Conceptual through Mature) and Level of Detail in the Cost Assessment (Actual through Goal)**

Cost Estimate Rating	A Mature	B Commercial	C Demonstration	D Pilot	E Conceptual (Idea or Lab)
A. Actual	0	-	-	-	-
B. Detailed	-5 to +5	-10 to +10	-15 to +20	-	-
C. Preliminary	-10 to +10	-15 to +15	-20 to +20	-25 to +30	-30 to +50
D. Simplified	-15 to +15	-20 to 20	-25 to +30	-30 to +30	-30 to +80
E. Goal	-	-30 to +70	-30 to +80	-30 to +100	-30 to +200

Likely Cost Uncertainty

**Pilot Cost Versus Estimated Cost**

Life cycle cost of prototypes and demonstration systems tend to be dominated by single unit cost effects. These include: tooling cost, grid interconnection cost, and quality control issues leading to premature failure. To eliminate these effects on cost that are difficult to quantify, it was assumed the technology has failure rates consistent with products that have reached a reasonable amount of design maturity. Further, to minimize the impacts on total cost of one-off expenses such as tooling and grid interconnection, deployment was assumed to have a reasonable scale of 10 MW for wave, tidal, and ocean current technologies. River in-stream technology was assumed to have an installed capacity of 5 MW because these devices tend to have a smaller

rated capacity per unit deployed. These deployment scales represent early commercial adopter plants. Costs are high because they have not taken advantage of the economies-of-deployment scale experienced by other renewable technologies. Wind farms, for example, are deployed oftentimes at sizes greater than 100 MW.

### **Cumulatively Deployed Capacity—Impacts on Cost Reduction**

As with any renewable energy source, costs will decline as the cumulative experience of the industry increases. Learning curves have been used extensively to evaluate the future cost of emerging energy alternatives. A learning factor predicts what the likely cost will be every time installed capacity doubles. Historically, various renewable energy alternatives have shown learning rates between 75% (solar) and 85% (wind). These effects can be felt most dominantly in the early phases of technology deployment and will result in significant cost reductions in the short term. For the purpose of this assessment, it was assumed that no learning curve effects are present. Only effects of manufacturing multiple units for the plant itself were considered.

### **Cost Categories**

In order to quantify the economic and job-creation effects of MHK renewable technologies, all major life cycle costs need to be broken out in suitable cost categories. The project-specific data includes a bill of goods (costs associated with actual construction/installation of the system and facility, as well as costs for equipment and other services and fees required), annual O&M costs and data on the portion of expenditures spent locally, financing terms, and tax rates (if applicable), among others. More specifically, the model requires the following project inputs:

- Materials and equipment costs (electrical collector system, transmission cable, landing and grid interconnection, and balance of plant)
- Installation/labor costs (mooring and device, cable, and landing and grid interconnection)
- Permitting costs (engineering, legal, and permits)
- Annual O&M costs (personnel, materials, and services)
- Other parameters (e.g., financial—debt and equity, taxes, and land lease)

Unfortunately, as noted previously, many developers consider this type of information proprietary due to competitive forces in the marketplace. Similarly, project-specific differences can and do significantly impact costs. As a result, it is virtually impossible to identify a one-price-fits-all situation. Nevertheless, the model provides default values for each of the inputs noted above and all those necessary for the analysis.

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## Publicly Available MHK Cost Studies

The following documents are available at no cost from the EPRI website ([www.epri.com/oceanenergy](http://www.epri.com/oceanenergy)).

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